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Interaction of a plasma with a rough surface of a divertor plate*

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In this talk, I summarize the results of several earlier papers:

Ryutov, D.D. Contrib. Plasma Phys., **36**, 207 (1996).

Cohen, R.H., Ryutov, D.D. Phys. Plasmas, **5**, 2194 (1998).

Cohen, R.H., Cid, R.E., Hooper, E.B., Molvik, A.W., Porter, G.D. and Ryutov, D.D. Journ. of Nucl. Material, **266-269**, 258 (1999).

Cohen, R.H., Ryutov, D.D., Contrib. Plasma Phys., **40**, 456 (2000).

Three main ingredients of the problem:

1. Rough surface

2. Grazing magnetic field

3. Quasineutrality constraint

The question about the evolution of the surface “topography” under the action of the plasma flux is not a subject of our study.

The problem we address is a plasma physics problem: given some structure is present, what are the consequences in terms of the spatial, angular, and energy distributions of the ions and electrons near the surface?

By solving this part of the problem (in particular, by finding the fraction of the “wetted” surface), we provide the tools for studies of the processes occurring on a long time scale, such as the surface erosion.

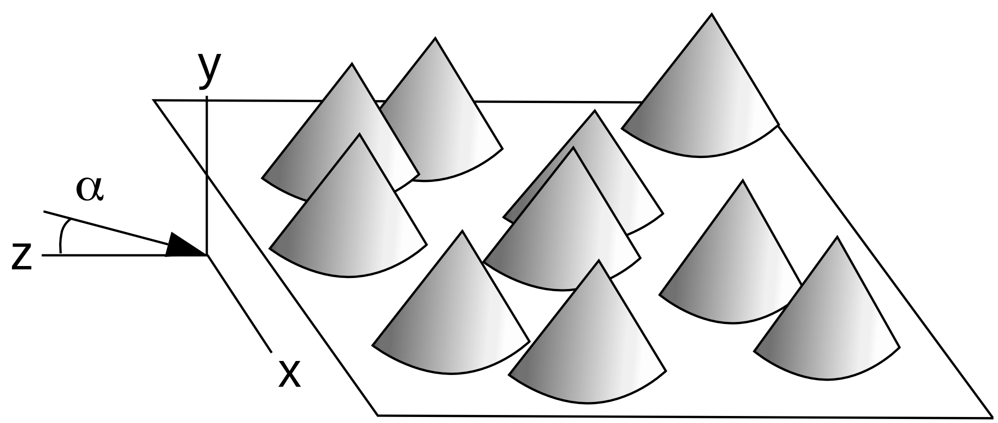
As an example consider the plasma with the parameters:

$T_e \sim T_i \sim 30$ eV, deuterium, $n \sim 3 \cdot 10^{13}$ cm^{-3}, $B \sim 3$ T

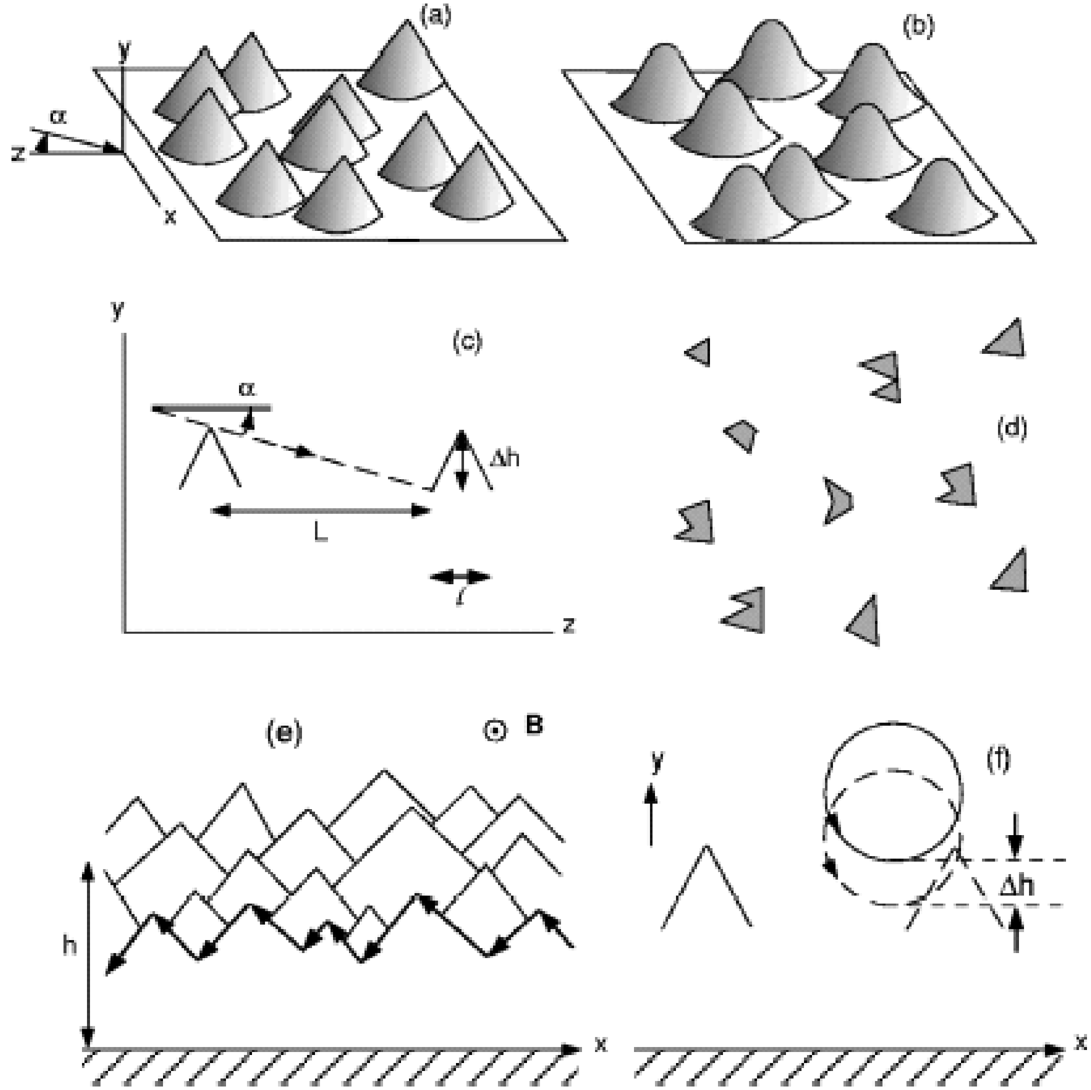
The particle gyroradii and the Debye radius are:

$\rho_i \sim 350$ μm, $\rho_e \sim 6$ μm, $\rho_D \sim 10$ μm

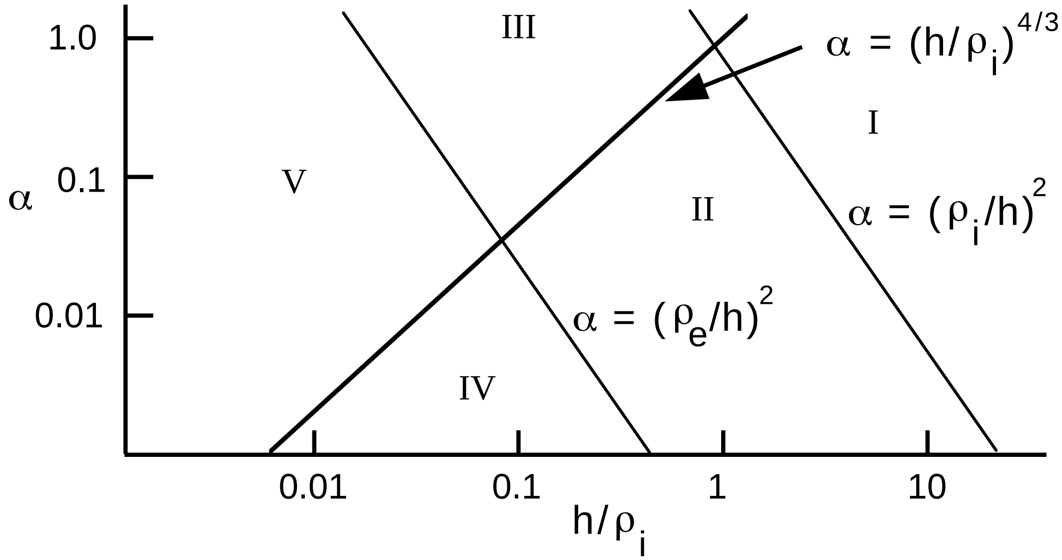
Plasma interaction with a rough surface depends on the relation between the height h of the surface features and these three spatial scales (ρ_i, ρ_e, and ρ_D)



Some geometrical features of the problem

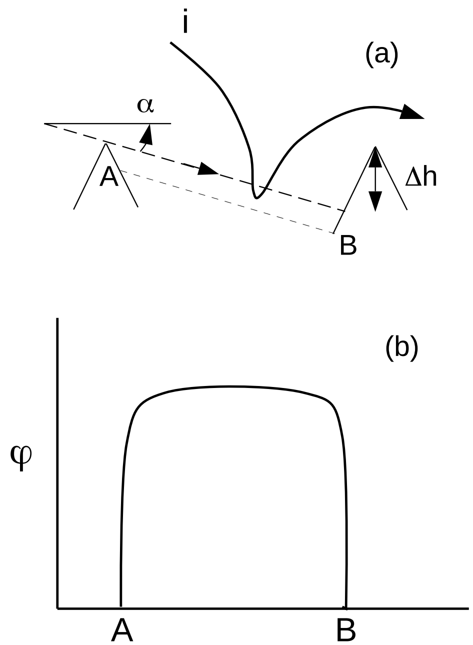


Summary of wetted area vs. regime



Domain	Fraction of surface wetted by ions	Fraction of surface wetted by electrons
I	α	α
II	$\alpha^{4/5}(\rho_i/h)^{2/5}$	α
III	$\alpha^{1/2}$	α
IV	$\alpha^{4/5}(\rho_i/h)^{2/5}$	$\alpha^{4/5}(\rho_e/h)^{2/5}$
V	$\alpha^{1/2}$	$\alpha^{4/5}(\rho_e/h)^{2/5}$

In most regimes, ions penetrate deeper beneath the mountain tops than the electrons (which are much more tightly tied to the magnetic field lines).



The quasineutrality constraint: potentials must form to prevent ions from entering the spatial domain inaccessible for electrons in the shadows of the mountain tops.

Therefore, with the quasineutrality constraint imposed, the area wetted by the ions will become equal to the area wetted by the electrons.

Formation of a cold neutralizing plasma in the “shadowed” zones restores an “independence” of plasma electrons and ions

SUMMARY

- A general methodology for evaluating the fraction of a wetted area for a divertor plate with a rough surface has been developed.
- It has been shown that the plasma particles reach only the tops of the bumps; accordingly, heat and particle flux are strongly localized.
- The fraction of a surface accessible for the electrons is typically smaller than that for the ions.
- In some regimes, the quasineutrality constraint leads to a significant ion reflection from the divertor plate (even if the plate material is perfectly absorbing).
- Formation of a cold neutralizing plasma in the shadows of the peaks makes these zones accessible for the ions. After neutralization has occurred, the ion albedo becomes zero.

- A surface roughness in a tilted magnetic field affects the secondary emission coefficient S (S can both increase and decrease compared to its value for a flat surface).

- The effects discussed above must be folded into any realistic assessment of the problems of the surface damage, erosion-redeposition, tritium retention, etc.